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Anderson

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(54) **TOUCHDOWN DETECTION**

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G11B 5/60 (2006.01)
G11B 21/21 (2006.01)

(52) **U.S. Cl.**
USPC **360/75**

(58) **Field of Classification Search**
None
See application file for complete search history.

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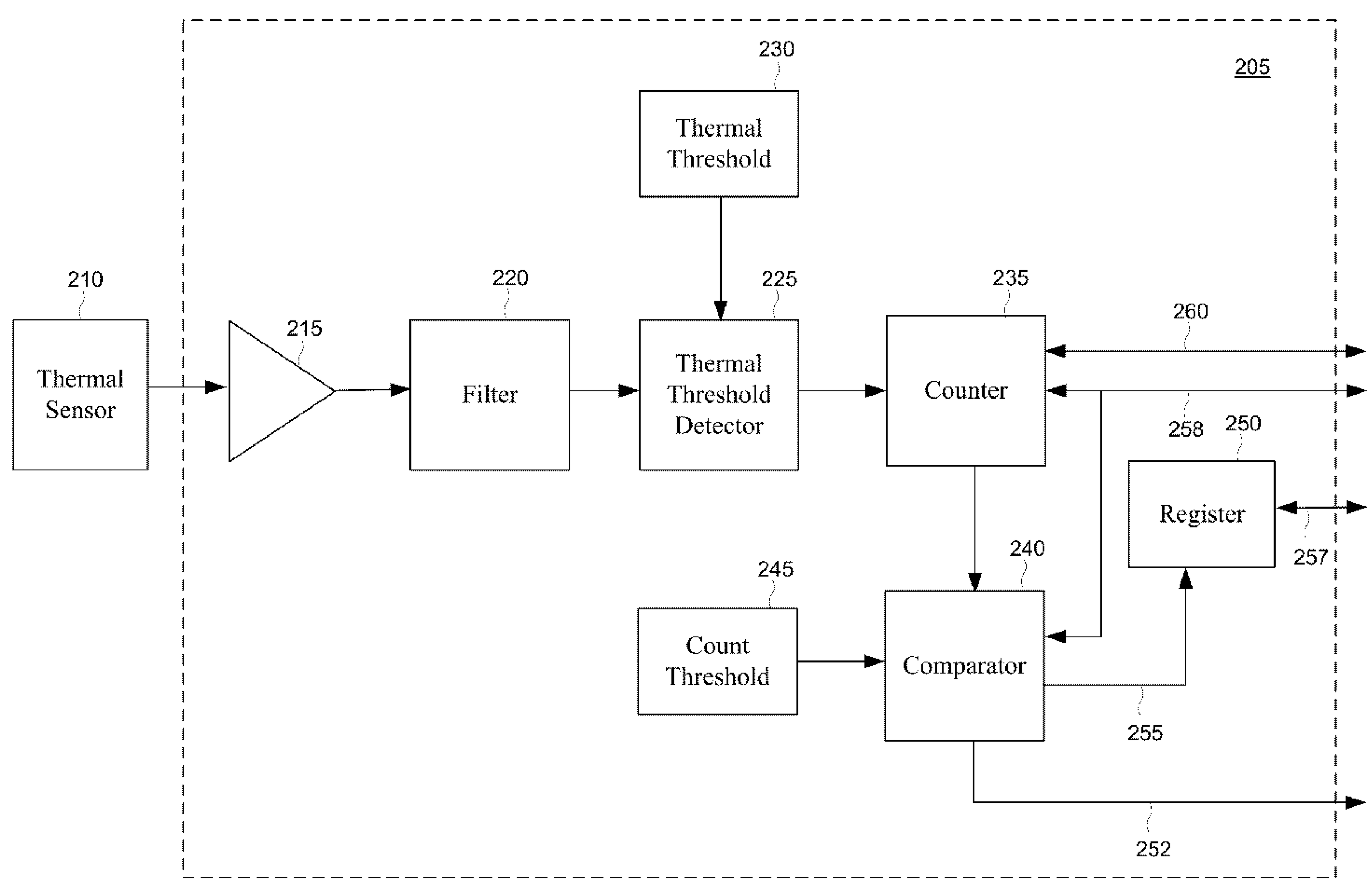
(57) **ABSTRACT**

Systems and methods for detecting touchdown of a head on a disk are provided. In one embodiment, a disk drive comprises a thermal sensor configured to sense a temperature of a head and to generate a thermal signal based on the sensed temperature. The disk drive also comprises touchdown circuit configured to receive the thermal signal, to increment a count value each time the thermal signal exceeds a thermal threshold, and to output a fault signal when the count value is equal to or exceeds a count threshold.

21 Claims, 9 Drawing Sheets



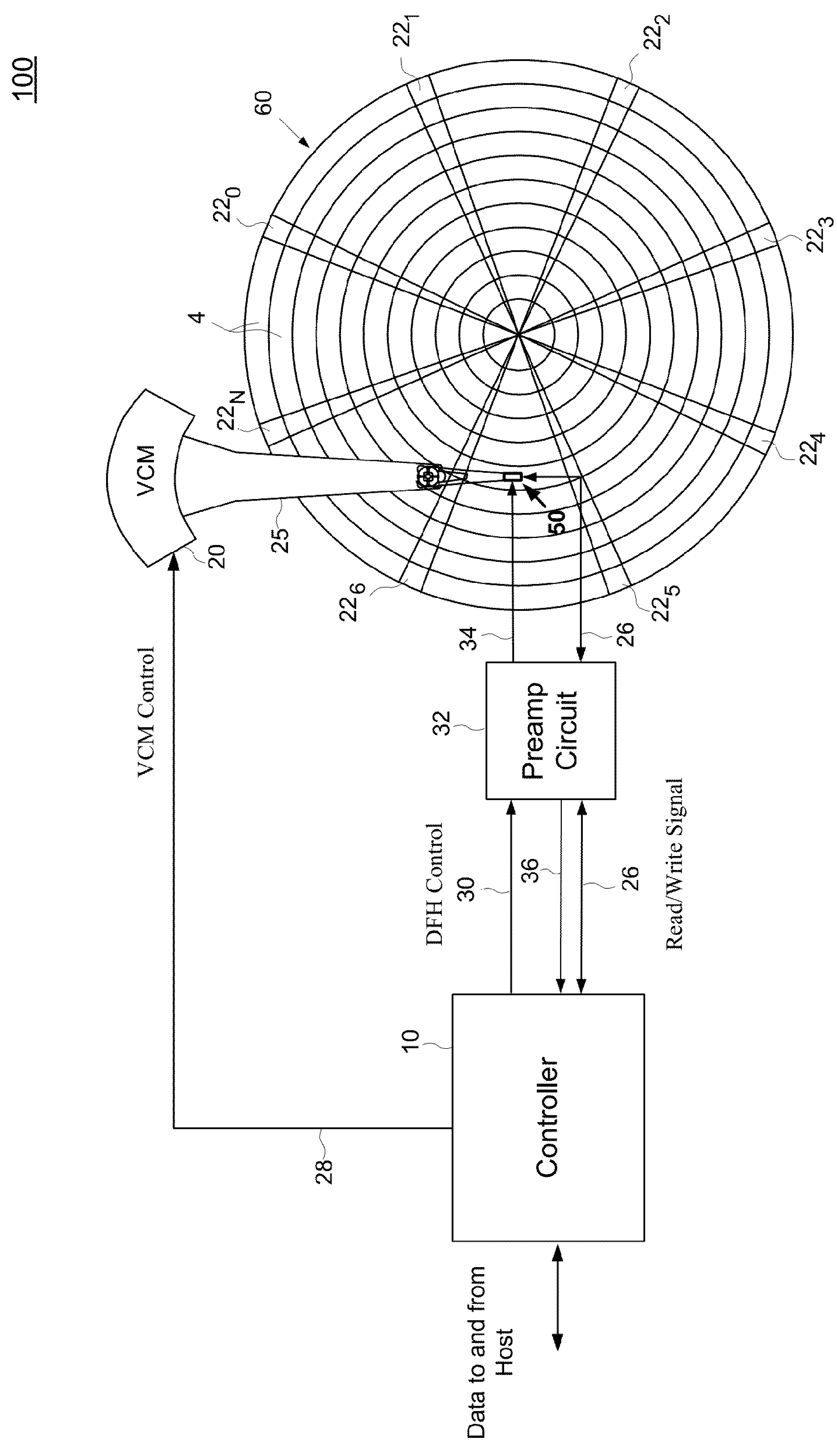

100
VCM
VCM Control
Controller
Preamp Circuit
DFH Control
Read/Write Signal
Data to and from Host

FIG. 1

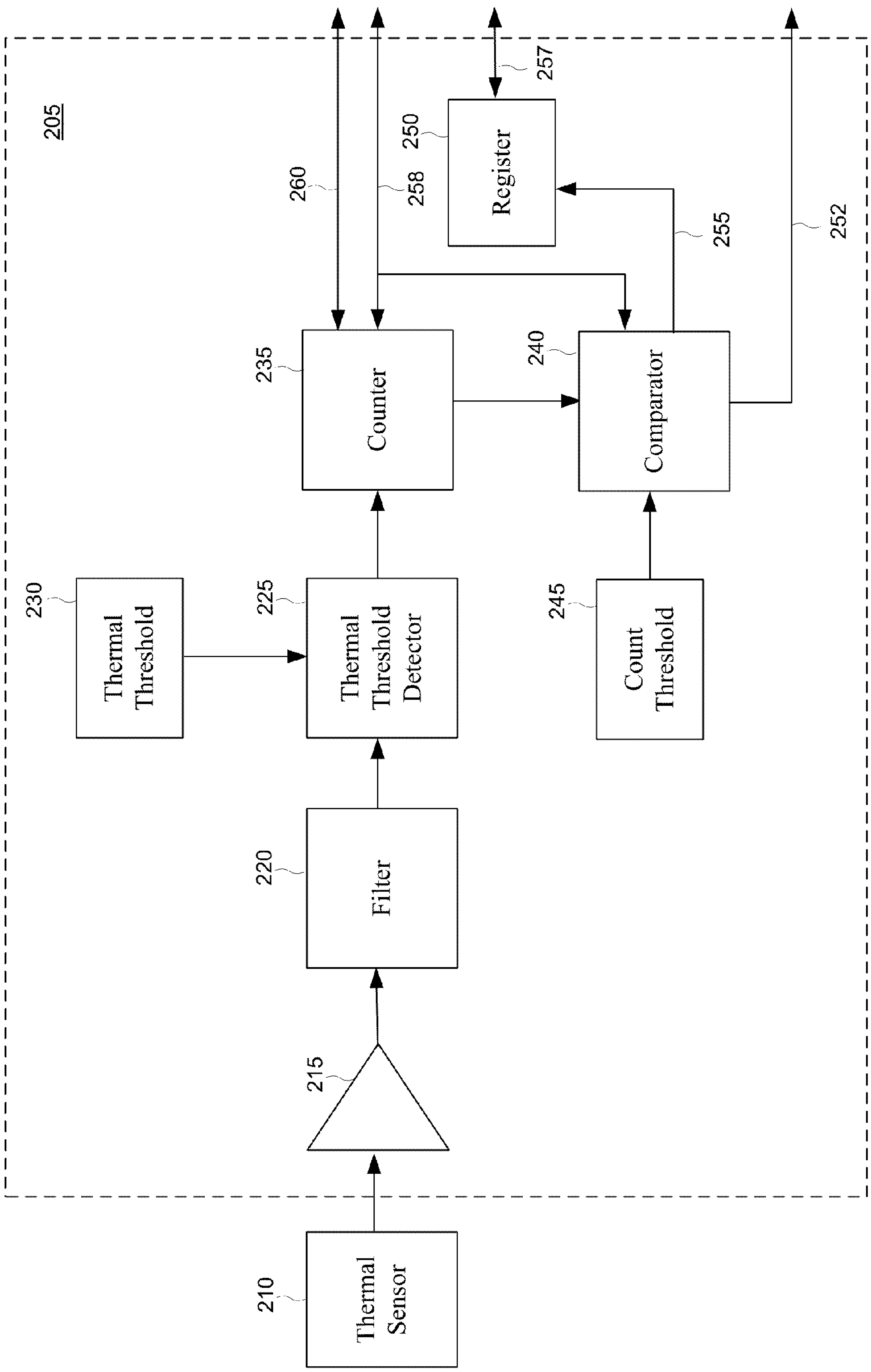

205
210
Thermal Sensor
215
220
Filter
225
Thermal Threshold Detector
230
Thermal Threshold
235
Counter
240
Comparator
245
Count Threshold
250
Register
252
255
257
258
260

FIG. 2

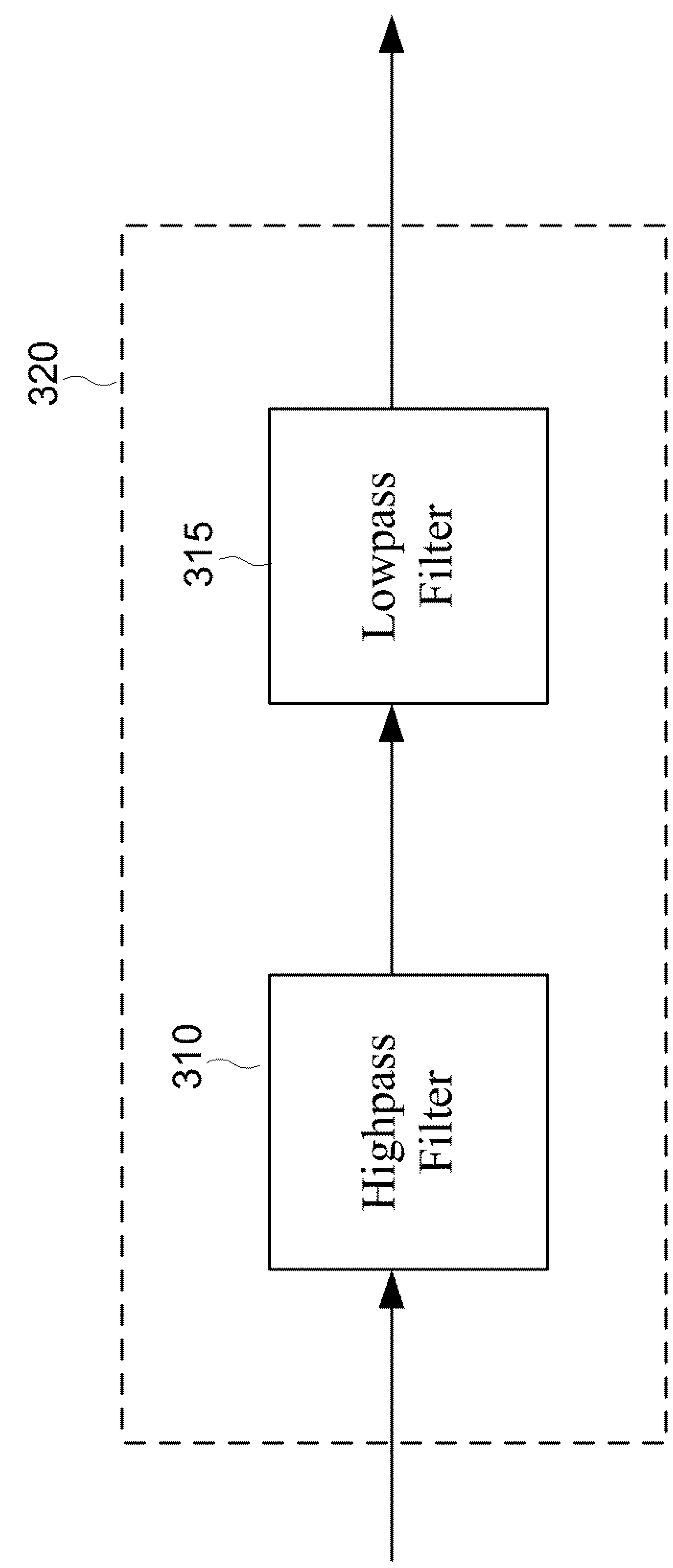


FIG. 3

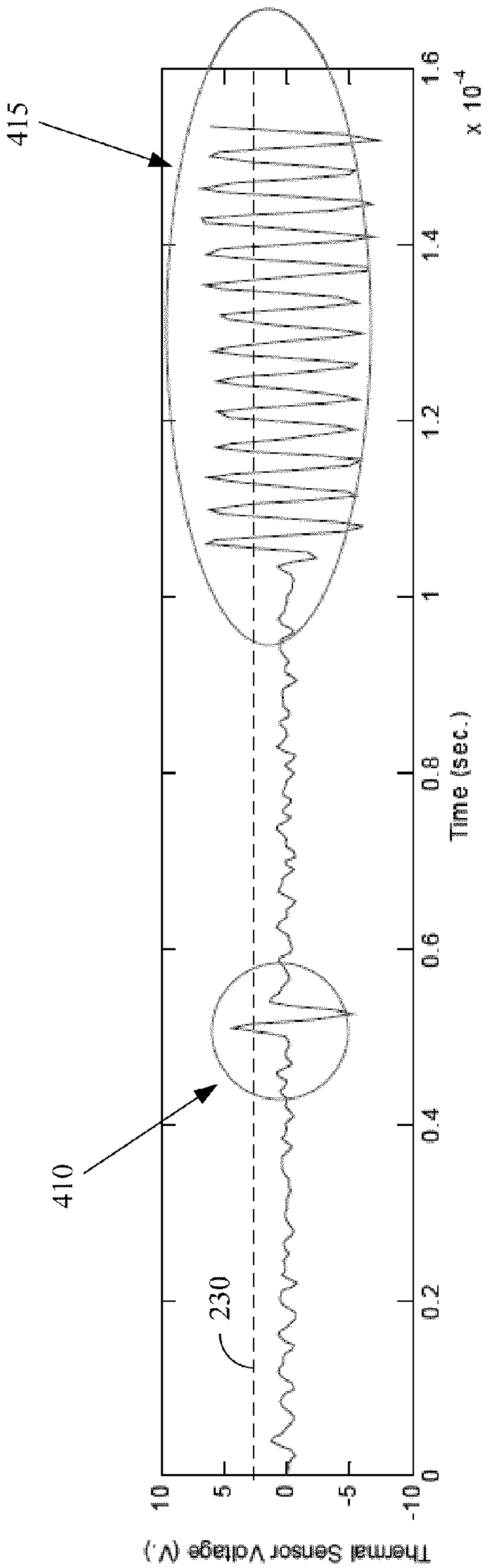

415
410
230
Thermal Sensor Voltage (V.)
Time (sec.)
x 10^-4

FIG. 4

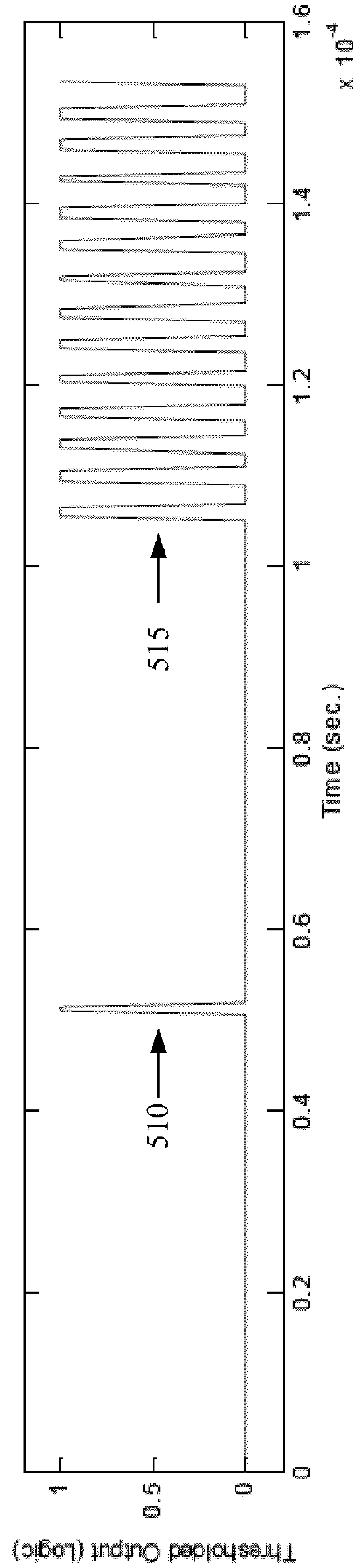

515
510
Thresholded Output (Logic)
Time (sec.)
x 10^-4

FIG. 5

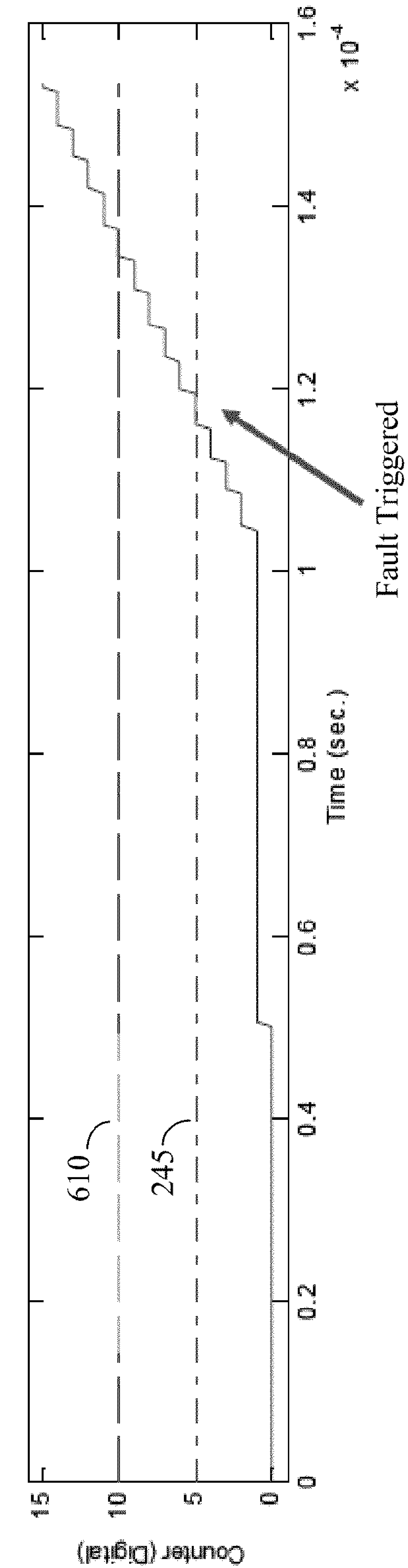

Counter (Digital)
0
5
10
15
Time (sec.)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
x 10^-4
610
245
Fault Triggered

FIG. 6

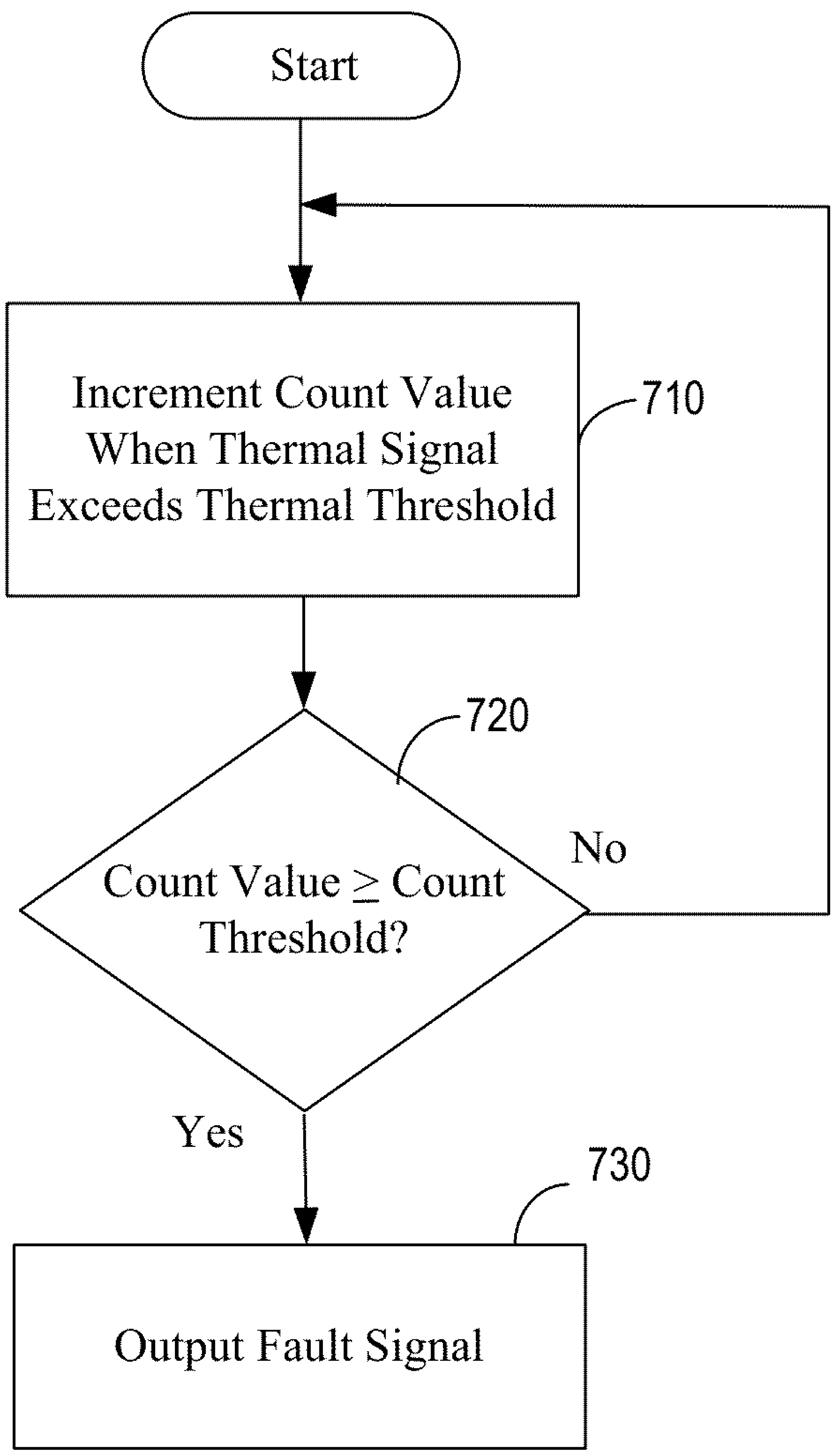

Start
Increment Count Value When Thermal Signal Exceeds Thermal Threshold
710
720
Count Value ≥ Count Threshold?
No
Yes
730
Output Fault Signal

FIG. 7

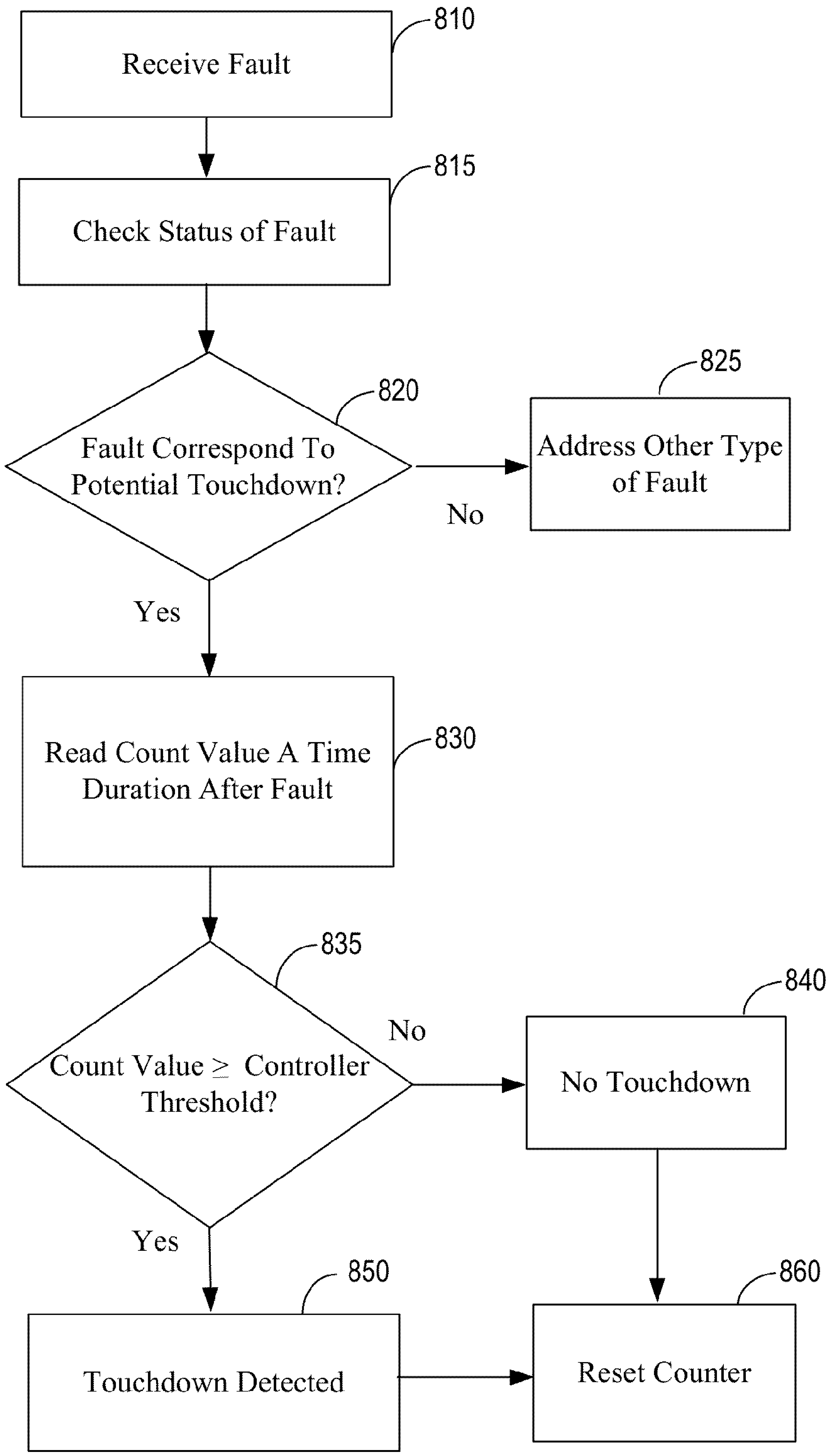

810
Receive Fault
815
Check Status of Fault
820
Fault Correspond To Potential Touchdown?
No
825
Address Other Type of Fault
Yes
830
Read Count Value A Time Duration After Fault
835
Count Value ≥ Controller Threshold?
No
840
No Touchdown
Yes
850
Touchdown Detected
860
Reset Counter

FIG. 8

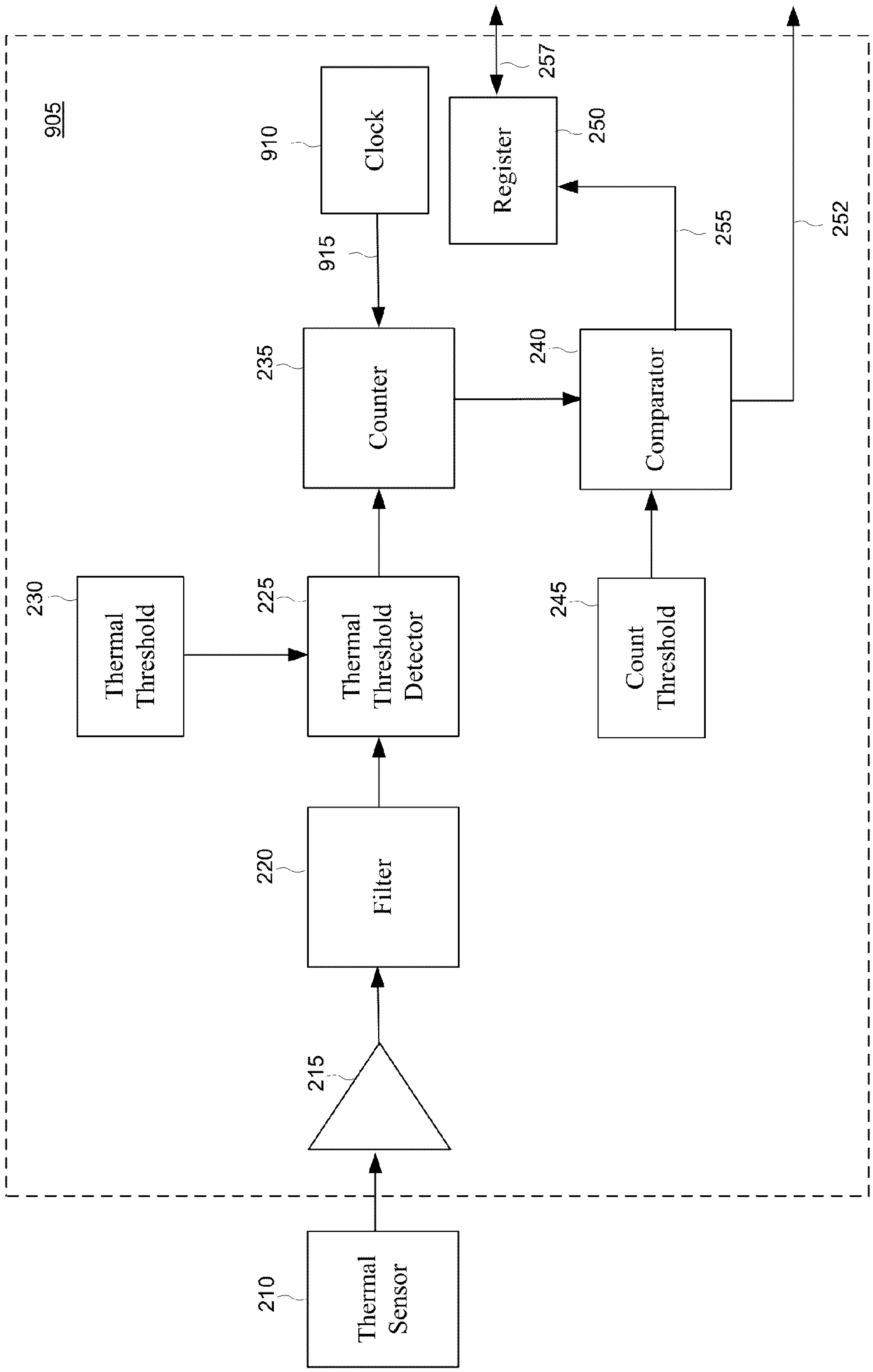

905
Clock
910
915
Register
250
257
255
252
Counter
235
Comparator
240
Thermal Threshold
230
Thermal Threshold Detector
225
Count Threshold
245
Filter
220
215
Thermal Sensor
210

FIG. 9

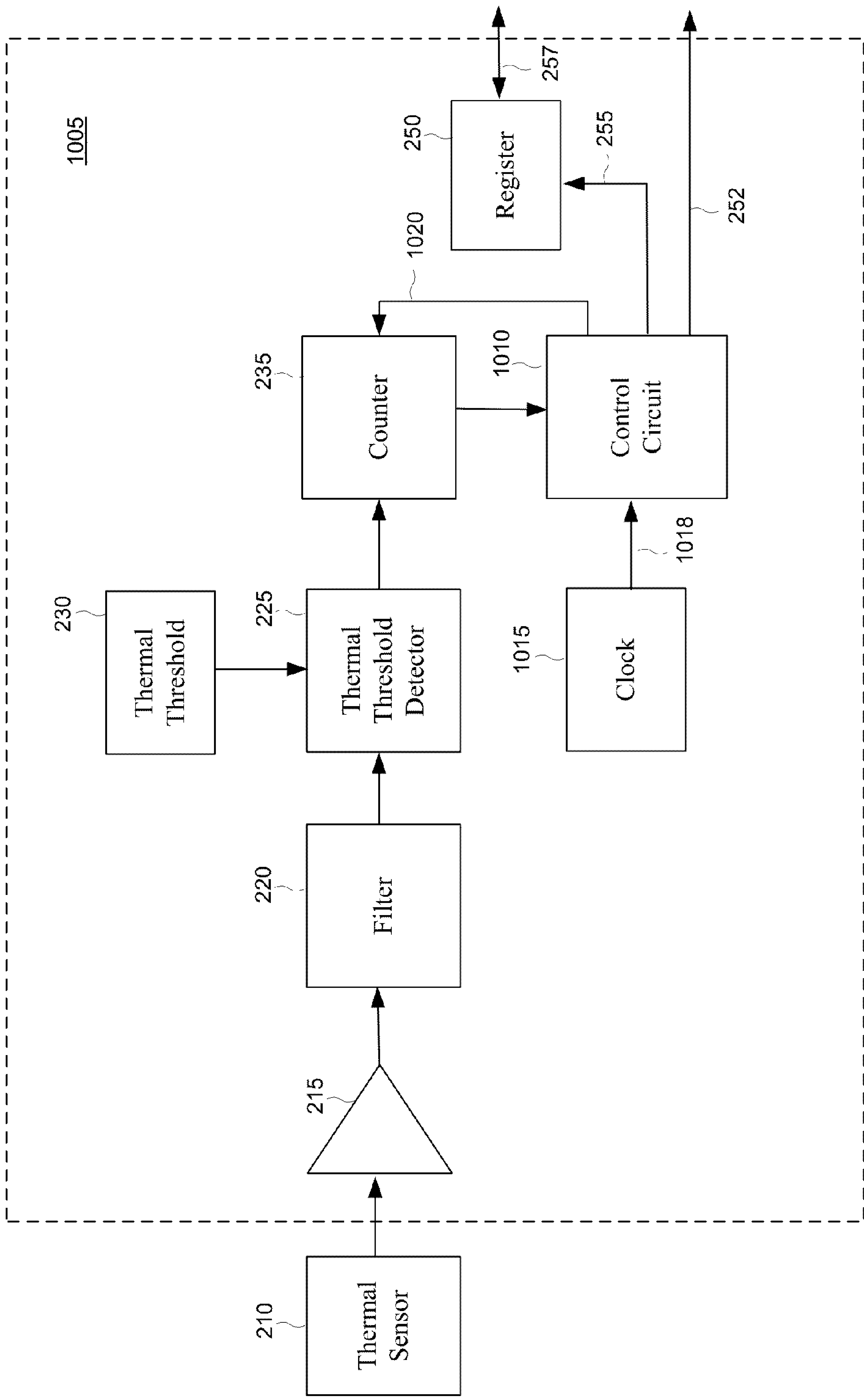

1005
Register
250
257
255
252
1020
Counter
235
Control
Circuit
1010
Thermal
Threshold
230
Thermal
Threshold
Detector
225
Clock
1015
1018
Filter
220
215
Thermal
Sensor
210

FIG. 10

TOUCHDOWN DETECTION

BACKGROUND

A disk drive comprises a rotating disk and a head over the disk to magnetically write to and read data from the disk. The head may be connected to a distal end of an actuator arm that is rotated about a pivot to position the head radially over the disk. During write/read operations, the head flies above the disk surface on a cushion of air formed by the rotating disk. The fly height of the head may be adjusted by a dynamic fly height (DFH) heater or other mechanism. When the head touches down on the rotating disk, the head and/or disk may be damaged. Therefore, it is desirable to detect touchdown of the head on the disk and to stop the detected touchdown to prevent damage to the head and/or disk.

BRIEF DESCRIPTION OF THE DRAWINGS

The accompanying drawings, which are included to provide further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description serve to explain the principles of the invention. In the drawings:

FIG. **1** is a block diagram of a disk drive according to an embodiment of the present invention;

FIG. **2** is a block diagram of a touchdown circuit according to an embodiment of the present invention;

FIG. **3** is a block diagram of a bandpass filter according to an embodiment of the present invention;

FIG. **4** shows an example of a filtered thermal signal plotted over time according to an embodiment of the present invention;

FIG. **5** shows an example of an output of a thermal threshold detector plotted over time according to an embodiment of the present invention;

FIG. **6** shows an example of a count value plotted over time according to an embodiment of the present invention;

FIG. **7** is a flow diagram illustrating a method for triggering a fault signal according to an embodiment of the present invention;

FIG. **8** is a flow diagram illustrating a method for determining whether there is touchdown in response to a fault signal according to an embodiment of the present invention;

FIG. **9** is a block diagram of a touchdown circuit according to another embodiment of the present invention; and

FIG. **10** is a block diagram of a touchdown circuit according to yet another embodiment of the present invention.

DETAILED DESCRIPTION

In the following detailed description, numerous specific details are set forth to provide a full understanding of the present invention. It will be apparent, however, to one ordinarily skilled in the art that the present invention may be practiced without some of these specific details. In other instances, well-known structures and techniques have not been shown in detail to avoid unnecessarily obscuring the present invention.

FIG. **1** shows a disk drive **100** according to an embodiment of the present invention. The disk drive **100** comprises a rotating magnetic disk **60** and a head **50** connected to the distal end of an actuator arm **25**. The actuator arm **25** is rotated about a pivot by a voice coil motor (VCM) **20** to position the head **50** radially over the disk **60**. The disk **60** comprises a number of concentric data tracks **4**, each of which may be partitioned into a number of data sectors (not shown). The disk **60** may also comprise a plurality of embedded servo sectors $\mathbf{22}_0$-$\mathbf{22}_N$, each of which may include position information that can be read from the disk **60** by the head **50** to determine the position of the head **50** over the disk **60**.

The disk drive **100** also comprises a controller **10** that performs various operations of the disk drive **100** described herein. The controller **10** may be implemented using one or more processors for executing instructions and may further include memory, such as a volatile or non-volatile memory, for storing data (e.g., data being processed) and/or instructions. The instructions may be executed by the one or more processors to perform the various functions of the controller **10** described herein. The one or more processors may include a microcontroller, a Digital Signal Processor (DSP), an Application Specific Integrated Circuit (ASIC), a Field Programmable Gate Array (FPGA), hard-wired logic, analog circuit and/or a combination thereof. The controller **10** may be located on a printed circuit board (PCB).

The controller **10** uses the head **50** to magnetically write data to and read data from the disk **60**. To write data to the disk **60**, the controller **10** processes the data into a write signal **26** and outputs the write signal **26** to the head **50**. The head **50** converts the write signal into a magnetic field that magnetizes the disk **60** based on the write signal, thereby writing the data to the disk **60**. To read data from the disk **60**, the head **50** generates a read signal based on the magnetization of the disk **60** and outputs the read signal **26** to the controller **10**. The controller **10** processes the read signal **26** into data. The controller **10** may write data to and read data from the disk **60** in respond to commands from a host device.

The disk drive **100** may also comprise a preamplifier circuit **32** for shaping and driving the write signal **26** to the head **50** and amplifying the read signal **26** from the head **50**. The preamplifier circuit **32** may be located on the actuator arm **25**, the VCM **20** or other location between the head **50** and the controller **10**. The preamplifier circuit **32** may also be integrated in the controller **10**.

The preamplifier circuit **32** may communicate a fault condition in the preamplifier circuit **32** to the controller **10** through a line **36** connected to a fault pin at the preamplifier circuit **32**. The fault condition may include an open and/or short circuit in the head **50** or other abnormality. Upon receiving a fault signal from the preamplifier circuit **32**, the controller **10** may interrogate the preamplifier **32** through an interface to determine the nature of the fault.

The disk drive **100** may also comprise a dynamic fly height (DFH) system (not shown) for adjusting the fly height of the head **50** above the disk **60**. The DFH system may comprise a heater that controls the fly height through thermal expansion. The controller **10** may control the fly height by sending a DFH control signal **30** to the preamplifier circuit **32** to adjust the current **34** to the heater.

FIG. **2** shows a touchdown circuit **205** according to an embodiment of the present invention. The touchdown circuit **205** detects touchdown of the head **50** on the disk **60** by detecting changes in the temperature of the head **50** that are indicative of touchdown. The touchdown circuit **205** may be included in the preamplifier circuit **32**, as discussed further below.

The touchdown circuit **205** receives a thermal signal from a thermal sensor **210** that is configured to sense a temperature of the head **50**. The thermal sensor **210** may comprise a thermister, a tunnel magneto resistive (TMR) sensor, a giant magneto resistive (GMR) sensor, or other type of sensor capable of sensing temperature. The thermal sensor **210** may be located at or proximate to the head **50** to sense the temperature of the head **50**. For example, the thermal sensor **210** may be embedded in the head **50**.

The touchdown circuit **205** comprises an amplifier **215**, a filter **220**, a thermal threshold detector **225**, a counter **235** and a comparator **240**. The amplifier **215** is configured to amplify the thermal signal from the thermal sensor **210**.

The filter **220** is configured to pass a portion of the thermal signal due to touchdown of the head **50** on the disk **60** and filter out other portions of the thermal signal due to background noise, ambient temperature, temperature of the DFH heater, and/or other unwanted sources. For example, touchdown of the head **50** on the disk **60** may cause the thermal signal to oscillate at one or more resonant frequencies of an air bearing surface of the head **50** and/or the disk **60**. In this example, the filter **220** may comprise a bandpass filter that passes the thermal signal within a frequency bandpass corresponding to the air bearing surface resonance. The air bearing surface resonance may be depend on the rotational speed of disk **60**, head geometry, stiffness of the head suspension, roughness of the disk surface and/or other factors. In this example, the bandpass of the bandpass filter may be selected to isolate the resonant frequencies from background noise, thereby improving the detection signal-to-noise ratio (SNR).

FIG. **3** shows an example of a bandpass filter **320** that may be used for the filter **220**. In this example, the bandpass filter **320** is implemented using a combination of a highpass filter **310** and a lowpass filter **315**. The highpass filter **310** may be a one-pole highpass filter having a cutoff frequency of approximately 50-500 KHz, and the lowpass filter **315** may be a three-pole lowpass filter having a cutoff frequency of approximately 200-2000 KHz. It is to be appreciated that the transfer functions of the highpass filter **310** and the lowpass filter **315** may have any number of poles and/or zeros. In one embodiment, the bandpass filter **320** may have a bandpass within a frequency range of approximately 50 KHz to 2000 KHz, and more particularly 100 KHz to 600 KHz.

Referring back to FIG. **2**, the thermal threshold detector **225** receives the filtered thermal signal from the filter **220** and a thermal threshold **230**. In one embodiment, the thermal threshold detector **225** compares the filtered thermal signal with the thermal threshold **230** and outputs a pulse signal each time the filtered thermal signal exceeds the thermal threshold **230**. The thermal threshold **230** may be outputted by a programmable digital-to-analog converter (DAC), which allows adjustment of the thermal threshold **230** by writing the thermal threshold to a register.

The counter **235** counts the number of pulses from the thermal threshold detector **225**, and hence the number of times that the filtered thermal signal exceeds the thermal threshold. Thus, the count value of the counter **235** is incremented by one count each time the filtered thermal signal exceeds the thermal threshold.

The comparator **240** receives the count value from the counter **235** and a count threshold **245**. The count threshold **245** may be adjusted by writing the count threshold to a register. The comparator **240** compares the count value with the count threshold **245** and outputs a fault signal **252** to the controller **10** when the count value is equal to or exceeds the count threshold **245**. In one embodiment, the fault signal **252** indicates potential touchdown of the head **50** on the disk **60**. In response to receiving the fault signal **252**, the controller **10** determines whether touchdown has actually occurred, as discussed below.

The controller **10** may determine whether there is touchdown by reading the count value from the counter **235** a time duration (e.g., 50 microseconds) after receiving the fault signal **252**, and determining whether the read count value is above the count threshold **245** by a certain amount. The higher the read count value is above the count threshold **245**, the greater the likelihood the fault signal **252** was triggered by touchdown of the head **50** on the disk **60** rather than spurious contact between the head **50** and the disk **60** and/or noise. This is because the count value increases at a much faster rate due to touchdown, as discussed further below. In this embodiment, the controller **10** may determine there is touchdown when the read count value is above the count threshold **245** by a certain amount (e.g., 5 counts) and may determine there is no touchdown when the read count value is not above the count threshold **245** by the certain amount.

In this embodiment, the counter **235** continues to count the number of pulses from the thermal threshold detector **225** after the fault signal **252** is sent to the controller **10**. This allows the controller **10** to later read the count value from the counter **235** the time duration (e.g., 50 microseconds) after receiving the fault signal **252** and determine how much the count value has increased above the count threshold during that time. The controller **10** may read the count value from the counter **235** via line **260**. After making a determination whether there is touchdown, the controller **10** may reset the counter **235** to zero to reset the touchdown circuit **205** to detect another touchdown. The counter **235** may also automatically reset when the controller **10** reads the count value from the counter **235**.

In one embodiment, the comparator **240** may be a one-shot comparator that outputs the fault signal **252** one time when the count value from the counter **235** initially reaches the count threshold **245**. After making a determination whether there is touchdown in response to the fault signal **252**, the controller **10** may reset the one-shot comparator in addition to resetting the counter **235**. The controller **10** may reset both the comparator **240** and the counter **235** by sending a reset signal **258** to the comparator **240** and the counter **235**. Alternatively, the controller **10** may reset a control bit in a register **250** that causes the comparator **240** and the counter **235** to reset.

In one embodiment, when the count value is equal to or exceeds the count threshold **245**, the comparator **240** may write a fault status message in a register **250** indicating that the fault signal **252** was triggered by potential touchdown. After receiving the fault signal **252**, the controller **10** may read the fault status message from the register **250** via a communication line **257** to determine whether the fault signal **252** was triggered by potential touchdown. For example, the controller **10** may receive the fault signal **252** along with other fault signals triggered by other events, e.g., abnormalities in the preamp circuit **32**, on a shared fault line. By reading the fault status message from the register **250**, the controller **10** is able to indentify the nature of a received fault signal, and therefore distinguish the fault signal **252** from other fault signals received on the shared fault line.

In one embodiment, the counter **235** may be configured to saturate when the maximum count value of the counter **235** is reached. This way, the counter **235** does not wrap-around to zero when the maximum count value of the counter **235** is reached. In this embodiment, the controller **10** may reset the counter **235** after making a determination whether there is touchdown.

An example illustrating operation of the touchdown circuit **205** according to an embodiment will now be described with reference to FIGS. **4** to **6**.

FIG. **4** shows an example of the filtered thermal signal plotted over time, in which the thermal signal has been bandpass filtered by the filter **220**. In this example, the filtered thermal signal includes an isolated peak **410** due to spurious contact between the head **50** and the disk **60**. The filtered thermal signal also includes a sequence of peaks **415** due to touchdown of the head **50** on the disk **60**. For the example in which touchdown causes the thermal signal to oscillate at one or more resonant frequencies of the air bearing surface, the peaks **415** may occur at a rate corresponding to one of the resonant frequencies of the air bearing surface.

FIG. **4** also shows an example of a thermal threshold **230** that may be used by the thermal threshold detector **225**. The thermal threshold **230** may be set to a level that allows the thermal threshold detector **225** to detect peaks **415** in the filtered thermal signal due to touchdown while minimizing false detections due to noise and/or other unwanted sources.

FIG. **5** shows an example of the thermal threshold detector **225** output plotted over time, in which the filtered thermal signal and the thermal threshold shown in FIG. **4** are inputted to the thermal threshold detector **225**. In this example, the thermal threshold detector **225** outputs a single pulse **510** corresponding to the isolated peak **410** due to spurious contact. The thermal threshold detector **225** also outputs a sequence of pulses **515** corresponding to the peaks **415** due to touchdown.

FIG. **6** shows an example of the count value of the counter **235** plotted over time resulting, in which the pulses shown in FIG. **5** are inputted to the counter **235**. In this example, the counter **235** is initially set to zero. As shown in FIG. **6**, the single pulse **510** corresponding to spurious contact causes the count value to increase by one count. The pulses **515** corresponding to touchdown cause the count value to quickly increase and reach the count threshold **245**, at which point the fault signal **252** is triggered and sent to the controller **10**. As shown in FIG. **6**, the count value continues to increase due to the touchdown after the fault signal **252** is triggered.

A time duration after receiving the fault signal **252**, the controller **10** may read the count value from the counter **235** to determine whether the read count value exceeds the count threshold **245** by a certain amount. The controller **10** may do this, for example, by determining whether the read count value is equal to or exceeds a controller threshold **610** that is set above the count threshold **245**, as shown in FIG. **6**. If the read count value is equal to or above the controller threshold **610**, then the controller **10** may determine there is touchdown. Otherwise, the controller **10** may determine there is no touchdown.

The read count value allows the controller **10** to distinguish between a fault signal **252** triggered by touchdown of the head **50** on the disk **60** and a fault signal **252** triggered by the accumulation of many spurious contacts between the head **50** and the disk **60** over time. This is because the read count increases at a much faster rate, and is therefore more likely to equal or exceed the controller threshold **610**, when the fault signal **252** is triggered by touchdown. In the example shown in FIG. **6**, the count value reaches the controller threshold **610** about **20** microseconds after the fault signal **252** is triggered, indicating that the fault trigger **252** was likely triggered by touchdown. In this example, if the controller **10** reads the count value a time duration of 20 microseconds or more after receiving the fault signal **252**, then the controller **10** determines there is touchdown.

FIG. **7** is a flow diagram illustrating a method for triggering a fault signal according to an embodiment. The method may be performed by the touchdown circuit **205**.

In step **710**, a count value is incremented when a thermal signal exceeds a thermal threshold. The thermal signal may be a based on a temperature of the head **50** sensed by the temperature sensor **210**. Step **710** may be performed by the thermal threshold detector **225**, which detects when the thermal signal exceeds the thermal threshold, and by the counter **235**, which increments the count value when the thermal threshold detector **225** detects that the thermal signal exceeds the thermal threshold.

In step **720**, a determination is made whether the count value is equal to or exceeds the count threshold. This step may be performed by the comparator **240**. If the count value is equal to or exceeds the count threshold, then the method proceeds to step **730**. Otherwise, the method returns to step **710**.

In step **730**, a fault signal is outputted. The fault signal may be outputted to the controller **10**, which determines whether there is touchdown in response to receiving the fault signal.

FIG. **8** is a flow diagram illustrating a method for determining whether there is touchdown according to an embodiment. The method may be performed by the controller **10** in response to receiving a fault signal **252** from the touchdown circuit **205**.

In step **810**, a fault signal is received. For example, the controller **10** may receive the fault signal from the touchdown circuit **205**. In step **815**, a status of the fault is checked to identify the nature of the fault signal. For example, the controller **10** may read a fault status message from the register **250** to determine the nature of the fault signal. In step **820**, a determination is made whether the fault signal received in step **810** was triggered by potential touchdown based on the status check in step **815**. For example, the controller **10** may determine whether the fault signal corresponds to potential touchdown based on the fault status message read from the register **250**. If the fault signal corresponds to potential touchdown, then the method proceeds to step **830**. Otherwise, the method proceeds to step **825**, in which another type of fault is addressed.

In step **830**, the count value is read a time duration after the fault signal. For example, the controller **10** may read the count value from the counter **235**, which continues to run after the fault signal. In step **835**, a determination is made whether the read count value is equal to or exceeds a controller threshold. The controller threshold is set above the count threshold in step **720** of FIG. **7**. If the read count value is equal to or exceeds the controller threshold, then touchdown is detected in step **850**. Otherwise, no touchdown is detected in step **840**. In both cases, the counter **235** is reset to detect another touchdown in step **860**. When touchdown is detected in step **850**, the controller **10** may take steps to stop the touchdown, for example, by increasing the fly height of the head **50**.

The controller **10** may use other methods to determine whether there is touchdown. In one embodiment, the controller **10** may measure a time duration between the time the controller **10** receives the fault signal **252** and the time the controller **10** last reset the counter **235**, and determine whether there is touchdown based on the length of the time duration. The shorter the time duration, the greater the likelihood that the fault signal **252** was triggered by touchdown rather than an accumulation of spurious contacts and/or noise over time. This is because touchdown causes the count value to increase faster, and therefore trigger the fault signal faster. In this embodiment, the controller **10** may determine whether there is touchdown by comparing the time duration to a time threshold. If the time duration is equal to or below the time threshold, then the controller **10** may determine that there is touchdown. If the time duration is above the time threshold, then the controller **10** may determine there is no touchdown. Alternatively, if the time duration is above the time threshold, then the controller **10** may use the method in FIG. **8** to determine whether there is touchdown. This allows the controller **10** to detect a touchdown event that may have occurred a long time duration since the last counter reset.

The time threshold may be determined, for example, experimentally by measuring the time it takes the accumulation of spurious contacts to trigger the fault signal in one or more trials, and setting the time threshold below the measured time. The time threshold may also be determined by adjusting the time threshold until a number of false touchdown alarms is reduced below a certain level. Other methods may also be used to set the time threshold.

In one embodiment, the touchdown circuit **205** may be integrated in the preamplifier circuit **32** of the disk drive **100**. To facilitate integration of the touchdown circuit **205** in the preamplifier circuit **32**, the touchdown circuits **205** may include any one or more of the following advantages.

One advantage is that the touchdown circuit **205** does not require a clock or a large integration capacitor to measure a time duration. This is because the controller **10** can measure the time duration between the fault signal **252** and the count value read from the counter **235**. By not requiring a clock, the touchdown circuit **205** avoids the generation of a clock signal in the preamplifier circuit **32**, which may feed into other signals in the preamplifier circuit **32** and interfere with the operation of the preamplifier circuit **32**.

Another advantage is that the touchdown circuit **205** may send the fault signal **252** to the controller **10** through the same fault pin used by the preamplifier circuit **32** to communicate other fault signals to the controller **10**. This is because the controller **10** can read the fault status message from the register **250** to determine the nature of a received fault signal, and therefore distinguish the fault signal **252** from other fault signals sent through the shared fault pin. As a result, the touchdown circuit **205** can be integrated in the preamplifier circuit **32** using an existing interface for communicating fault signals from the preamplifier circuit **32** to the controller **10**.

FIG. **9** shows a touchdown circuit **905** according to another embodiment of the present invention. In this embodiment, the touchdown circuit **905** comprises the amplifier **215**, the filter **220**, the thermal threshold detector **225**, the counter **235** and the comparator **240**. In addition, the touchdown circuit **905** comprises a clock **910**.

In this embodiment, the clock **910** generates a clock signal **915** that periodically resets the counter **235** to prevent the fault signal **252** from being triggered by an accumulation of spurious contacts over time instead of touchdown. In this embodiment, the controller **10** may automatically determine there is touchdown when the controller **10** receives the fault signal **252**. To minimize false touchdown alarms, the time period between counter resets by the clock **910** may be set to a time duration that is short enough to prevent the count value from reaching the count threshold **245** due to an accumulation of spurious contacts over time instead of touchdown.

For the embodiment in which the touchdown circuit **905** is integrated in the preamplifier circuit **32**, the clock **910** may operate at a lower frequency than the read/write signals **26** to minimize interference in the preamplifier circuit **32**.

The control circuit **905** may also receive a clock signal to periodically reset the counter **235** from an external source, in which case the clock **910** may be omitted. For example, the touchdown circuit **905** may receive a servo gate signal, which has a period of one servo wedge, and reset the counter **235** based on the servo gate signal. In this example, the time period between counter resets may be set to an integer multiple of servo wedges. Other periodic signals may also be used to reset the counter **235**.

FIG. **10** shows a touchdown circuit **1005** according to another embodiment of the present invention. In this embodiment, the touchdown circuit **1005** comprises the amplifier **215**, the filter **220**, the thermal threshold detector **225** and the counter **235**. In addition, the touchdown circuit **1005** comprises a control circuit **1010** and a clock **1015**.

The control circuit **1010** receives the count value from the counter **235** and a clock signal **1018** from the clock **1015**. The control circuit **1010** is configured to detect touchdown, and to output the fault signal **252** to the controller **10** upon detecting touchdown. In one embodiment, the control circuit **1010** detects touchdown by reading the count value from the counter **235** a time duration after the counter **235** is reset and determining whether the count value is equal to or above a certain threshold. The control circuit **1010** measures the time duration using the clock signal **1018** from the clock **1015**. In this embodiment, the control circuit **1010** may determine there is touchdown when the count value after the time duration is equal to or above the threshold, and determine there is no touchdown when the count value after the time duration is below the threshold. After making the determination whether there is touchdown, the control circuit **1010** may reset the counter **235** via reset signal **1020** to restart the process.

The control circuit **1010** may also determine whether there is touchdown by determining a time duration for the count value from the counter **235** to reach a certain amount (e.g., 5 counts), and comparing the time duration with a time threshold. If the time duration is equal to or below the time threshold, then the control circuit **1010** may determine there is touchdown and if the time duration is above the time threshold, then the control circuit **1010** may determine there is no touchdown. The control circuit **1010** measures the time duration using the clock signal **1018** from the clock **1015**. After making a determination whether there is touchdown, the control circuit may reset the counter **235** and restart the process.

In this embodiment, the controller **10** may take steps to stop touchdown in response to receiving the fault signal **252**. For example, the controller **10** may stop the detected touchdown by increasing the fly height of the head **50**. The control circuit **1010** may also send a fault status message to the register **250** indentifying the fault as touchdown.

In this embodiment, the control circuit **1010** may measure the time duration using the clock signal **1018** from the clock **1015**. Alternatively, the control circuit **1010** may receive a clock signal from an external source, in which case the clock **1015** may be omitted. The control circuit **1010** may use any periodic signal as a clock signal to measure the time duration, such as the servo gate signal discussed above or other periodic signal.

The description of the invention is provided to enable any person skilled in the art to practice the various embodiments described herein. While the present invention has been particularly described with reference to the various figures and embodiments, it should be understood that these are for illustration purposes only and should not be taken as limiting the scope of the invention.

There may be many other ways to implement the invention. Various functions and elements described herein may be partitioned differently from those shown without departing from the spirit and scope of the invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and generic principles defined herein may be applied to other embodiments. Thus, many changes and modifications may be made to the invention, by one having ordinary skill in the art, without departing from the spirit and scope of the invention.

A reference to an element in the singular is not intended to mean "one and only one" unless specifically stated, but rather "one or more." The term "some" refers to one or more. Underlined and/or italicized headings and subheadings are used for convenience only, do not limit the invention, and are not referred to in connection with the interpretation of the description of the invention. All structural and functional equivalents to the elements of the various embodiments of the invention described throughout this disclosure that are known or later come to be known to those of ordinary skill in the art are expressly incorporated herein by reference and intended to be encompassed by the invention. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the above description.

What is claimed is:

1. A disk drive, comprising:

a thermal sensor configured to sense a temperature of a head and to generate a thermal signal based on the sensed temperature; and

a touchdown circuit configured to receive the thermal signal, to increment a count value each time the thermal signal exceeds a thermal threshold, and to output a fault signal when the count value is equal to or exceeds a count threshold.

2. The disk drive of claim **1**, wherein the thermal sensor comprises a thermistor or tunnel magneto resistive (TMR) sensor.

3. The disk drive of claim **1**, further comprising a controller configured to receive the fault signal, and to determine whether there is disk touchdown in response to the fault signal.

4. The disk drive of claim **3**, wherein the controller is configured to determine whether there is disk touchdown by reading the count value from the touchdown circuit a time duration after receiving the fault signal, and determining whether there is disk touchdown based on the read count value.

5. The disk drive of claim **4**, wherein the controller is configured to determine whether there is disk touchdown based on the read count value by determining there is disk touchdown when the read count value is above the count threshold by a certain amount.

6. The disk drive of claim **3**, wherein the controller is configured to determine whether there is disk touchdown by measuring a time duration between a time that the count value was reset and a time that the controller received the fault signal, and determining there is disk touchdown when the time duration is below a certain amount.

7. The disk drive of claim **3**, wherein the controller is configured to increase a height of the disk head above a disk when the controller determines there is disk touchdown.

8. The disk drive of claim **3**, wherein the controller is configured to reset the count value when the controller determines there is no disk touchdown.

9. The disk drive of claim **1**, wherein the touchdown circuit comprises:

a filter configured to filter the thermal signal;

a thermal threshold detector configured to output a pulse signal each time the filtered thermal signal exceeds the thermal threshold; and

a counter configured to increment the count value each time the thermal threshold detector outputs the pulse signal.

10. The disk drive of claim **9**, wherein the filter is configured to pass the thermal signal within a frequency range corresponding to an air bearing surface resonance.

11. The disk drive of claim **10**, wherein the filter has a bandpass within a frequency range of 50 KHz to 2000 KHz.

12. The disk drive of claim **1**, wherein the touchdown circuit comprises a control circuit configured to receive a clock signal, to measure a time duration based on the clock signal, to read the count value after the time duration, and to output the fault signal when the read count value is equal to or exceeds the count threshold.

13. The disk drive of claim **12**, wherein the touchdown circuit comprises a clock configured to generate the clock signal.

14. A method for detecting touchdown of a head on a disk in a disk drive, comprising:

sensing a temperature of the head;

generating a thermal signal based on the sensed temperature;

incrementing a count value each time the thermal signal exceeds a thermal threshold; and

generating a fault signal when the count value is equal to or exceeds a count threshold.

15. The method of claim **14**, further comprising determining whether there is disk touchdown in response to the fault signal.

16. The method of claim **15**, wherein the determining whether there is disk touchdown comprises:

reading the count value a time duration after the fault signal; and

determining whether there is disk touchdown based on the read count value.

17. The method of claim **16**, wherein the determining whether there is disk touchdown based on the read count value comprises determining there is disk touchdown when the read count value is above the count threshold by a certain amount.

18. The method of claim **15**, wherein determining whether there is disk touchdown comprises:

measuring a time duration between a time that the count value was reset and a time of the fault signal; and

determining there is disk touchdown when the time duration is below a certain amount.

19. The method of claim **14**, further comprising filtering the thermal signal, wherein the incrementing the count value comprises incrementing the count value each time the filtered thermal signal exceeds the thermal threshold.

20. The method of claim **19**, wherein the filtering the thermal signal comprises passing the thermal signal within a frequency range corresponding to an air bearing surface resonance.

21. The method of claim **20**, wherein the filtering the thermal signal comprises bandpass filtering the thermal signal within a frequency range of 50 KHz to 2000 KHz.

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